BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

SUBJECT: Potential Satellite Servicing Operations and the Impact of Servicing on Satellite Design
Case 730

DATE: July 31, 1969

FROM: M. H. Skeer

ABSTRACT

Previous studies have examined factors influencing the cost of satellite servicing and the potential satellite servicing market. Herein discussion is devoted to the impact of satellite servicing on the satellite system per se. Principal issues addressed are:

- To what level is servicing practical?
- How are satellite payloads and subsystems affected by servicing accommodations?

Some preliminary observations in this regard are:

- Current satellites are to a considerable extent modular in nature for ease of integration and assembly. Principal impact of servicing on satellite design would probably be repackaging for ease of accessibility.
- Until such time that a sophisticated space servicing base is available, satellite servicing operations most likely will principally involve replacement at the modular level.
- Many types of subsystem components may be replaced without precise standardization of interfaces, whereas others are highly sensitive to tolerances and must be precisely tuned to the system. It is speculated that there may be a tendency towards less modularity for subsystems by comparison to sensors, as governed by fine tuning for performance optimization.
- Development of mechanisms for replenishment of on-orbit expendables appears achievable with relatively modest changes to existing hardware.
- Outmoded or dormant satellites have valuable components which are capable of reuse or which contain useful data on subsystem wearout and degradation. Recovery of such subsystems would be a worthwhile servicing operation.
- From a long range viewpoint, new satellite concepts can be conceived which will allow exploitation of servicing capabilities including repair, maintenance, and updating in orbit.

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MEMORANDUM FOR FILE

1. INTRODUCTION

A capability to maintain, repair and update satellites in orbit can have a profound effect on the design and use of these systems. Extended satellite lifetimes, larger, more sophisticated satellites, and satellite "buses" capable of being updated in orbit are possible examples.

Previous studies have examined factors influencing the cost of satellite servicing (1) and survey the potential satellite servicing market (2). Herein examples are given of satellite servicing operations and factors which must be considered to make these operations practical. Cases cited in Section 3 are intended to give the reader an indication of some of the attendant problems associated with typical servicing tasks. Section 4 notes satellite design requirements, discusses examples of the impact of servicing on some existing satellites, and offers some speculation on future satellite design. Factors related to the overall servicing problem as for example servicing transportation, facilities, crew systems, docking and rendezvous systems, special tools, etc., have been discussed in part elsewhere (1,3-8) and are only summarized briefly herein.

2. STUDY APPROACH

Principal issues addressed in this memorandum are:

- To what level is servicing practical?
- How are satellite payloads and subsystems affected by servicing accommodations?

Issues relating to satellite servicing are explored by examination of specific servicing situations. Satellite servicing can accomplish a number of specific tasks. These include:

[(1)]Number in parenthesis corresponds to Reference number in list of References.

- Replacement or repair of malfunctioning components and payloads
- Recovery of valuable subsystems
- Replenishment of subsystem and experiment expendables
- Satellite modification and updating.

In each case an example which is representative of sensors or subsystems having numerous mechanical, electrical and thermal interfaces with the satellite is selected for consideration of potential servicing operations.

With the advent of on-orbit servicing, substantial changes in the design of satellites can result. To appreciate the implications of these changes, several examples are considered.

- Advanced Princeton Astronomy Experiment - repackaged in modular form for accessibility for servicing
- Nimbus satellite - reconfigured for servicing

Totally new concepts which can extend satellite performance are also briefly highlighted.

3. POTENTIAL SERVICING TASKS

3.1 Repair, Replacement, and Updating of Sensors

3.1.1 Sensor Repair and Replacement - The IRIS Sensor

The IRIS sensor (Figure 1) is a major experiment flown on the Nimbus satellite. Its purpose is to remotely determine the vertical temperature profile, water vapor concentration and other constituents of the earth's atmosphere vital to improved weather forecasting and mapping. The significance of the experiment prompted selection of the IRIS as a subject for detailed analysis of sensor servicing requirements and options. (9).

On the current Nimbus B flight the IRIS has suffered a mild degradation in performance as a result of two anaomalies:

- The instrument runs 4° to 5°F above design temperature.

- Optics misalignment occurred in orbit after initial setup and operation.*

These anomalies lend themselves to possible satellite servicing operations.

The extreme sensitivity of IRIS instrumentation would probably preclude most on-orbit repairs and modifications other than complete module replacement. For example:

- Internal optics alignment requires 1 1/2 days in the best laboratory environment with experienced personnel.

- Several days are required to locate and fix the precision components in need of repair during which time oscilloscopes and recorders are employed in step by step circuit traces for functional checks.

- Repair of electrical connections would require the extensive use of soldering. Alternative contact connections which could avoid this would result in an order of magnitude increase in circuit size and reduced reliability.

- To achieve accessibility to components at least double the volume would be required.

- Because of highly specialized tasks and skills necessary to make repairs, personnel training has been a major problem area. Currently, repairs are made only by the most experienced personnel.

- IRIS/Nimbus interfaces (shown in Figure 2) can readily be redesigned to accept on-orbit module removal and installation. No position tolerance problems relative to the satellite should be incurred and instrument shutdown in orbit does not appear to be bothersome.

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*The result of these anomalies is 30% degradation in the quality of data. This however is still an acceptable performance level. The experiment has achieved the expressed goal of demonstrating the feasibility of remote temperature and constituent soundings.

The noted temperature anomaly is a malfunction that might be fixed in orbit without module replacement by providing additional radiating area. Thermal coatings are close to the optimum available and could not be significantly improved or modified to reduce the operating temperature. Accessibility would pose no problem here. In contrast, the optics alignment problem would require module replacement because of alignment sensitivity and inaccessibility of components. (Incorporation of automatic alignment was considered at one point but discarded since added system complexity was not deemed worthwhile.)

3.1.2 Sensor Updating - The IRIS Sensor

Modifications to the IRIS instrumentation to extend the use of the satellite might be desirable on several counts. Detector sensitivity could be improved, and the viewing spectrum extended to cover the $.5\mu$ to 100μ range (from the current 5μ to 50μ range) with the advent of new detector materials. Replacement of the detector would necessitate substitution of a substantially modified optics unit. No satellite interfacing problems should result, however, so that on-orbit installation of an updated IRIS instrument module would be achievable. On-orbit updating of IRIS instrument electronics, as for example, the analog to digital converter, could also be accommodated within current interface constraints. Other improvements such as increasing resolution would necessitate increased power and therefore could not be incorporated without attendent on-orbit modifications to the satellite.

3.2 Recovery of Valuable Subsystems

3.2.1 Nimbus SNAP 19 Radioisotope Thermionic Generator (RTG) and Tape Recorders

When the Nimbus 1 flight was aborted due to launch vehicle failure the RTG was recovered from the ocean and reused on the successfully launched Nimbus B satellite. Recurring cost of the RTG is approximately one million dollars (approximately 10% of total satellite cost) which is principally attributable to the Plutonium-238 fuel element. Figures 3 and 4 respectively show the detailed configuration of the RTG and its relationship with respect to the satellite. Note the direct accessibility to the subsystem and the relatively simple attachment interfaces. Weight of the RTG is 30 lbs and should not pose handling problems.

Radioactivity level is low although possible packaging precautions would be required due to high (350°C) operating temperatures. Since the fuel element has essentially unlimited lifetime the RTG unit could have numerous reuses.

The tape recorder is another example of a reusable Nimbus subsystem. Recurring cost of tape recorders are 250K per unit with several units required for redundancy. Refurbishment of a tape recorder could probably be achieved for only 50K. However, due to the low cost it is not likely that a special trip to a satellite for tape recorder recovery would be justified. (More likely such a trip would be undertaken on other grounds.)

3.2.2 Retrieval of OSO Solar Panel

Reference 5 has considered servicing operations for the Orbiting Solar Observatory (OSO) shown in Figure 5. Figure 6 cites a list of items considered for retrieval in this study. These are principally sensors, optics modules, filters and detectors which could be retrieved for purposes of reuse, post flight analysis, or data acquisition. Retrieval of a solar panel, for example, is desirable for post flight analysis of surface degradation effects and semi-conductor degradation due to local changes in the crystal lattice. (The solar panel segment is 21" x 17" x 1" and weighs 10 lbs, and is fastened to the vertical structure by 21 screws which when freed expose wiring connecting the solar cells to a common terminal. The wiring is simply cut for solar panel removal.)

3.3 Replenishment of Expendables - OSO Pitch Gas Supply

Pitch stabilization of OSO is achieved by means of a cold gas reaction system to within $\pm$ 3 degrees of the sun line. The pitch gas expendable rate for OSO II, derived from OSO I data, was conservatively designed for greater than nominal OSO lifetime (6 months). Magnetic coupling with the earth's magnetic field was, however, more severe for OSO II and, as shown in Figure 7, expendables were depleted at a more rapid rate than had been anticipated.

The OSO II gas control system is shown in Figure 8. The pitch gas reservoir is a titanium bottle containing 4.4 lbs of nitrogen stored at 3,000 psia. Replenishment of the gas supply could be accomplished by attaching a new gas reservoir or by recharging the existing reservoir. The valve for replenishing the supply is readily accessible. (The procedure for performing pitch gas replenishment is delineated in detail in Reference 5.) Only modest changes in existing hardware should be required to accommodate this servicing operation.

3.4 Satellite Modification and Updating

3.4.1 TACOMSAT Repeater

In Reference 12 the TACOMSAT communications repeater (transponder) system was selected for detailed examination for possible servicing applications. Figures 9 and 10 depict the TACOMSAT. A block diagram of part of the repeater is shown in Figure 11.

Currently the UHF receiver network (of the repeater) contains filters of 50 KHZ, 100 KHZ and 425 KHZ bandwidths. The human voice by comparison has a bandwidth of 2.4 KHZ. If a 3 KHZ filter could be introduced in lieu of the 50 KHZ filter a 13 lb increase in signal to noise ratio would result. Because of low power requirements, operation with filters only slightly wider than voice bandwidths are attractive for emergency mode operations. If ground equipment with precise frequency standards becomes available it would be desirable to incorporate a 3 KHZ filter in the repeater subsystem. With on-orbit servicing this would be achieved by replacement of an existing filter.

The repeater components are mounted on the lower surface of the despun shelf. At present the repeater system would not be convenient for servicing since it is totally enclosed within the outer cylinder of solar cells. Access to the satellite interior could be provided by hinged solar panels. An on-the-pad servicing operating which in some respects simulated on-orbiting servicing conditions was undertaken which involved replacement of an electronic component located on the despun platform similar to the repeater components. To gain access, a solar panel was lifted and a working platform inserted in the open area between the cone and platform sections. Repair time took 2-3 hours after a troubleshooting time of several days.

Almost all components of the repeater system could be replaced individually and be expected to work, though perhaps in a non-optimum fashion. The repeater subsystems are tested separately, and then "tuned" together by adjusting component characteristics and matching impedences. The best measure of system tuning is power output from the power summer, whereby circuit characteristics are modified until power is maximized.

3.4.2 TACOMSAT Antenna

Possible modification on a larger scale was considered for other subsystems, as for example replacement of the antenna (Figure 12). Principal antenna interfaces with the satellite are mechanical (the electrical interface is simply a cable) and on-orbit modifications of this nature should be feasible. This is not to say that such a change is recommended. Experience suggests that for experimental satellites such as TACOMSAT, evolutionary changes and updating are usually accompanied by substantial redesign. The question is not one of feasibility but rather if modest updatings are justified. Antenna modification may be a more attractive possibility for long life satellites (i.e., Intelsat IV).

4. IMPACT OF ON-ORBIT SERVICING ON SATELLITE DESIGN

4.1 Satellite Servicing Design Requirements

Servicing can impose design requirements on a satellite which may significantly add to satellite complexity. As noted in Reference 1 it will be necessary to incorporate:

- checkout and telemetry systems to identify and transmit failure data,
- a spares inventory at the service base,
- emergency attitude control,
- rendezvous and docking systems,
- accessible components (by EVA or IVA),
- replaceable expendables, and possibly
- a working volume to enclose serviceable experiments and components.

Specific requirements are dependent on the particular satellite to be serviced. Desired lifetime, flexibility or performance and cost constraints all enter into the decision as to what degree these requirements are to be incorporated.

4.2 Experiment Reconfiguration - Telescope Maintenance and Updating

In Reference 6 a study has been undertaken to "develop conceptual packaging designs and hardware concepts to facilitate (on-orbit) maintenance, repair, and replacement of the instrument section of a 1 meter telescope." This study is concerned with a large complex grouping of optical and electrical components (as distinct from a small separate package such as IRIS cited earlier).

The OAO Princeton Experiment was used as the baseline. No redesign of the experiment was attempted; rather the study was confined to determining the degree of modularization desirable based on meeting optical tolerance constraints. Principal issues addressed were:

- Selection of optical system modules
- Analysis of module alignment tolerances
- Determination of the modularization effect on system performance.

The procedure utilized to accomplish this is delineated in Figure 13. Figure 14 shows a schematic of the modularized Princeton experiment instrumentation package in which case the entire instrument unit can be extended from the telescope container and rotated on a track for maximum accessibility. Figures 15 and 16 depict possible means of servicing in this mode via EVA.* A servicing platform and hangar volume are shown integrated with the satellite structure. The experiment package was optimally divided into 18 separate modules (11 different types in all) the largest of which was 55 lbs (Figure 17). It was concluded that with modularization "tolerances well within the minimum requirements for optimum functioning of the system can be achieved" and that "modularization which allows for replacement of any or all of

*The shroud, in Fig. 16, could be designed to completely enclose the experiments and it also could be pressurizable from the service vehicle. This would permit IVA servicing.

the parts of the system can be accomplished without compromising the structural, mechanical, or optical integrity of the system as a whole." These conclusions must be considered tentative, however, since factors such as added complexities of thermal design and contamination were not addressed quantitatively.

4.3 Satellite Configuration - Effects of Servicing Nimbus in Orbit

In Reference 13 the Nimbus satellite was reconfigured to accommodate satellite servicing for the purpose of assessing impact of servicing operations. Figure 18 shows a comparison of the current Nimbus design and the reconfigured concept. Figure 19 illustrates the main sensor ring in greater detail. It was found that the existing Nimbus design already exhibits extensive modularity which has been incorporated to facilitate systems integration during design, manufacturing, and test. Also, dense packaging was achieved to permit maximum weight and volume utilization within the launch vehicle envelope. Since subsystem modularity was inherent in the current design, principal modifications for servicing entailed structural reconfiguration to enhance ease of accessibility. Features of the service version of Nimbus are summarized below:

- The equipment has been reconfigured for packaging in uniform modular containers. Principal structural sections such as the main sensor ring and attitude control housing have been increased in volume.
- The solar array drive system which is packaged integrally with the housing unit in the existing design has been relocated in a separate accessible assembly.
- Connectors and equipment are readily accessible via access doors.
- Insulation is segmented and bonded to the movable access panels.
- Access areas are free of cabling and harnesses.
- Access panels are mounted on hinges or are readily removable.
- Captive fasteners are extensively utilized.

Results of this study suggest that little additional design complexity (if any) accrues from servicing requirements, but considerably volumetric and weight penalties will be incurred to achieve accessibility.

By comparison, inspection of the synchronous orbit TACOMSAT packaging arrangement (12) reveals an extremely low packaging density relative to that of Nimbus. This is a result of the large available payload volume of the launch vehicle shroud. Consider that TIIIC launch capability to synchronous orbit is of the same order as that of low earth orbit satellite launch vehicles (Thorad-Agena for example). The TIIIC volume envelope is considerably larger, however. Consequently volume limitations are notably eased and this has been reflected in the design of TACOMSAT. For example, solar panel area for accommodation of the 1 kw power requirements was acquired by a larger outer satellite cylinder, rather than resorting to deployable panel concepts. Thus it appears that by comparison to Nimbus, servicing would not impose a significant weight penalty (for accessibility) to this type of satellite.

4.4 Extension of Satellite Capabilities

Satellite sensors share common systems support requirements; namely power, data transmission, command and control, pointing, environmental control, etc. Common carrier satellites can be conceived as limited extensions of existing satellites with a capability of accepting various sensors within constrained interface tolerances; or at the extreme, as bus type satellites with sensor/subsystem interfaces controlled by a computer to accommodate a wide variety of sensors.*

Reference 2 notes that three clases of orbits are utilized for most satellites: 1) near polar-sun synchronous, 2) synchronous-equatorial, and 3) low attitude-low inclination. Common carriers could be utilized in these orbits to collect sensors or other payloads on a single spacecraft for ease of servicing or updating. In effect, the satellite would be a large unmanned space station which could be reconfigured or reprogrammed to meet varying mission requirements. This would include a capability for modular additions or replacement of sensors and other payloads.

Possible features of a common carrier satellite include subsystems to provide long term flexibility such as:

- several levels of power and power redistribution,
- several communications links,

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*These concepts have been considered in part in Reference 15.

- variable data handling capability,
- active thermal control for variable heat loads,
- cg control via ballast repositioning,
- computer capable of regulating variable data handling and housekeeping functions, and
- possible incorporation of independent pointing modules to meet varied orientation and pointing control requirements.

As a small scale example, Figure 20 conceptually shows how Nimbus might be redesigned and reconfigured to accept a variety of modularized earth viewing sensor packages. (13) Here the existing solar cells and batteries have been replaced by an RTG unit sized for peak power requirements ensuring a long power supply lifetime and freeing the satellites from solar panel orientation constraints.

The sensors and subsystems have been grouped in two separate detachable modules with plug-in interface connectors. Subsystems have been packaged in individual, easily accessible compartments for servicing. Sensors can either be replaced individually on the sensor platform or the entire platform can be removed for major upratings. Since earth viewing sensors are of the same generic family, envelopes for supporting interfaces (power, ACS, telemetry, etc.) might in general be predictable for a broad range of sensor uprating requirements. Design of a common carrier capable of supporting multi-disciplinary sensors and experiments would be a far more ambitious undertaking than the Nimbus example.

5.0 SUMMARY AND OBSERVATIONS

Satellite servicing has been reviewed in the following context:

- To what level is servicing practical?
- How are satellite payloads and subsystems effected by servicing accommodations?

Some preliminary observations in this regard are summarized below:

I. Level of Potential Servicing Operations

- The IRIS example suggests that until such time that a very sophisticated space station servicing base is available, satellite servicing operations will principally involve module and instrument replacement. This is due to the high degree of technical skills and elaborate servicing equipment and checkout facilities required for more extensive repairs.

- Outmoded or dormant satellites have valuable components which are capable of reuse, or which contain useful data on subsystem wearout and degradation. Recovery of such subsystems can be accomplished more simply than other servicing operations since there is no requirement to provide a live satellite after servicing. Consequently a successful servicing operation could be realized with greater certainty.

- Development of mechanisms for on-orbit expendables resupply (as for example the OSO pitch valve and reservoir) appears achievable with relatively modest changes to existing hardware.

- Many types of subsystem components may be replaced without precise standardization of interfaces whereas others are highly sensitive to tolerances and currently must be precisely tuned to the system. If component replacement at some level of modularity is specified as a design constraint for ease of servicing either 1) in orbit or automated tuning can be incorporated, 2) tolerances of individual components must be standardized, or 3) off-optimum performance must be made acceptable (i.e., with regard to subsystems it may be desirable to design to a specified overall performance level and incorporate liberal tolerances for individual component mismatch. By comparison, for sensors, optimized performance is almost always desirable and precise tuning would be required). It is speculated that the net effect may be a tendency towards less modularity for subsystems compared to sensors as governed by performance optimization criteria.

- Satellite updatings such as sensor replacement and some classes of subsystem modification appear achievable without major redesigns to satellite hardware. The level of updating will be determined by interface constraints and therefore, in most instances, must be planned for (i.e., tuning requirements, power level, thermal control, data handling, etc).

II. Impact of Servicing on Satellite Design

- Servicing can impose design requirements on a satellite which may significantly add to satellite complexity. Specific requirements depend on the particular satellite to be serviced and can vary substantially.

- Large experiment packages such as telescope instrumentation can probably be configured for servicing in convenient modular form and meet constraints imposed by physical tolerance limitations. Impact of other factors such as complexities of thermal design and contamination of optical components remain to be established.

- Current satellites are to some extent modular in nature for ease of integration and assembly. Principal impact of servicing on satellite design is repackaging for accessibility. This can be costly in terms of additional volume and weight for densely packaged satellite, i.e., Nimbus. However some satellites such as TACOMSAT are designed with low density and repackaging penalties would be relatively small. Effects of other factors such as added complexity for checkout are not sufficiently understood at present.

- New satellite concepts can be conceived which will allow exploitation of servicing capabilities. For example a possible design concept for disciplinary satellites (such as Nimbus) is separation of payloads (sensors) and subsystem units to allow replacement of individual payload packages.

- Multi-disciplinary bus type satellites are a possible outgrowth of extensive satellite servicing capabilities. Such satellites could separate sensors or other payload from a common spacecraft bus which would supply power, data handling, communications, attitude control, etc. functions. For these satellites replacement of entire satellite payloads to meet changing mission needs is a distinct possibility.

In conclusion in this exercise nothing has been determined which would preclude feasibility of satellite servicing at some useful level of benefit. However, it must be recognized that many critical questions which have been addressed here in a necessarily cursory fashion can only be answered definitely by detailed design and hardware study efforts.

M. H. Skeer

1013-MHS-nma

Attachments

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2. Bosch, H. B., "Preliminary Survey of the Potential for Satellite Servicing," Memorandum for File, May 22, 1969.

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11. Macchia, D., "Trip Report - Conversations at GSFC on Satellite Servicing," Memorandum for File, May 15, 1969.

12. Macchia, D., and Skeer, M. H., "Trip Report - Potential On-Orbit Servicing of TACOMSAT and Intelsat IV Satellites," Memorandum for File, July 3, 1969.

13. Kiersarsky, A. S., "Effects of In-Orbit Servicing on Nimbus Configuration," Memorandum for File, July 18, 1969.

14. General Electric Company, Nimbus III Reference Manual, April, 1969.

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The IRIS is comprised of optics and electronics modules and has an overall weight of 32 lbs., 23 lbs. of which is in the optics module, and 9 lbs. in the electronics module. The overall dimensions of the optics and electronics modules are 15" x 13" x 8" and 8" x 6" x 6", respectively.

The IRIS is transported in an individual carrying case and is supported by means of 3 mounting screws. Three connectors establish all power and data links.

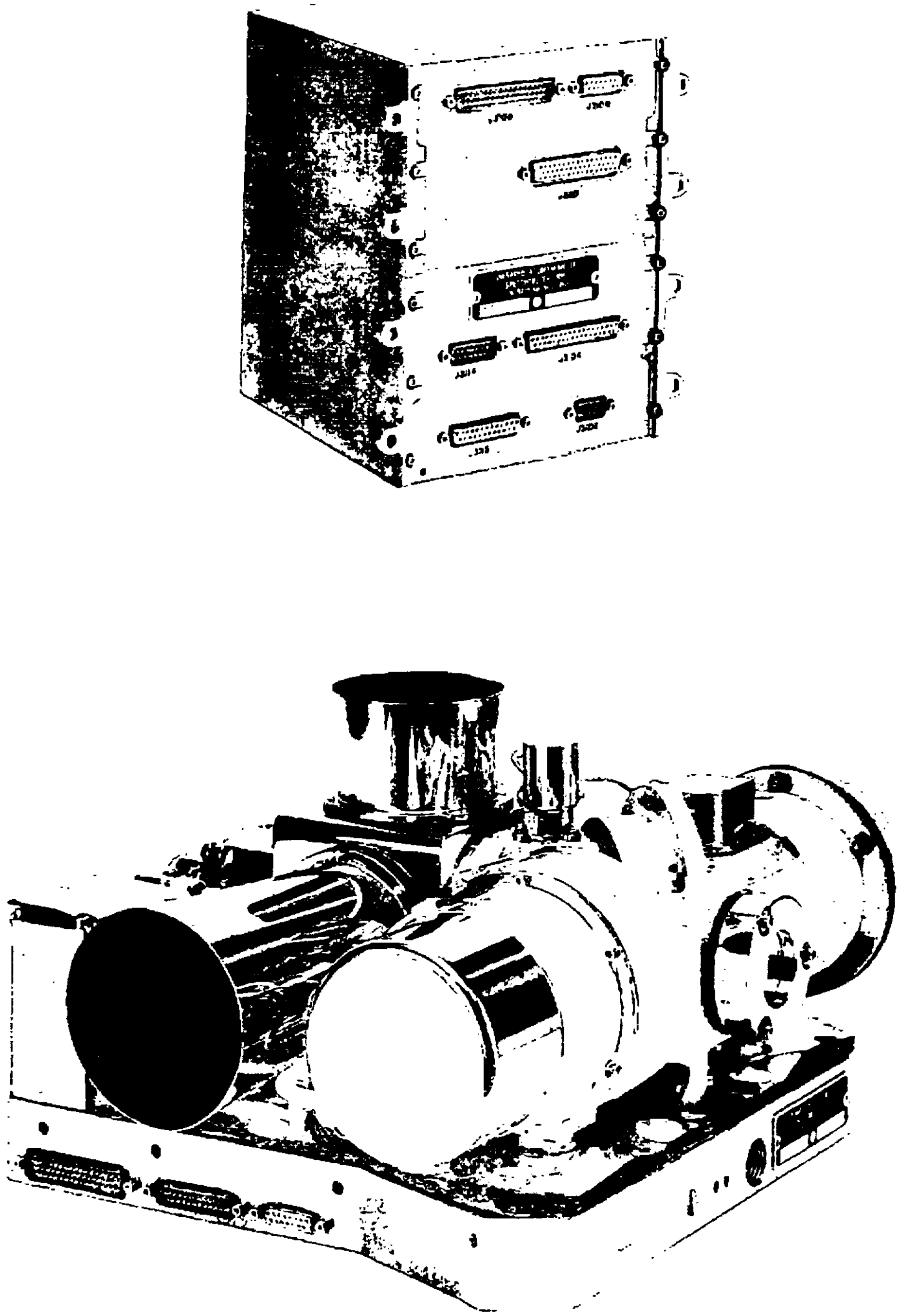
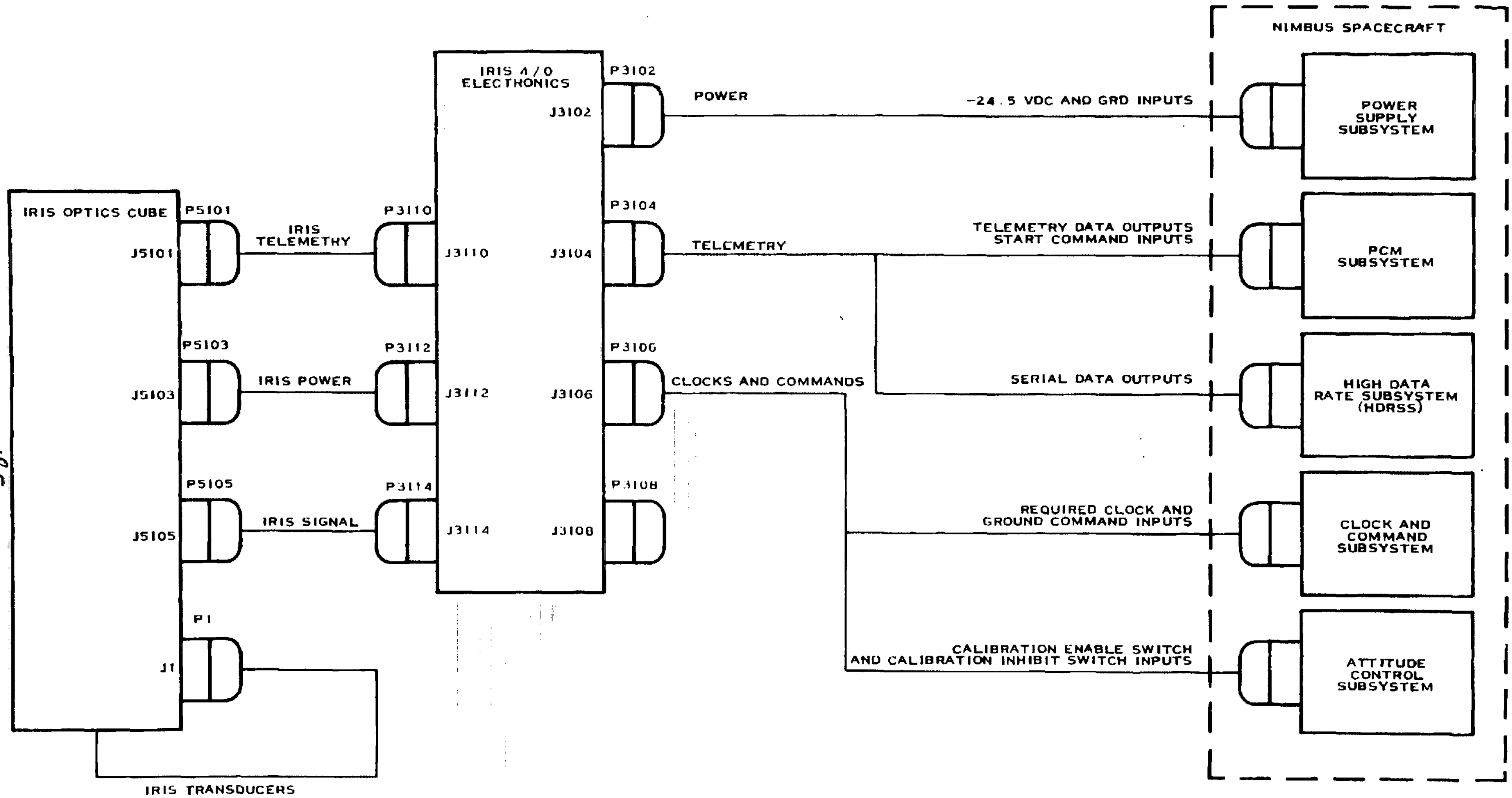


FIGURE 1 - IRIS INSTRUMENT



INSTRUMENT INTERFACES WITH NIMBUS

- PULSE CODE MODULATION SUBSYSTEM
- POWER SUPPLY SUBSYSTEM
- HIGH DATA RATE SUBSYSTEM
- ATTITUDE CONTROL SUBSYSTEM
- CLOCK AND COMMAND SUBSYSTEM

FIGURE 2 · IRIS, NIMBUS · HOOK-UP DIAGRAM (TEST AND FLIGHT)

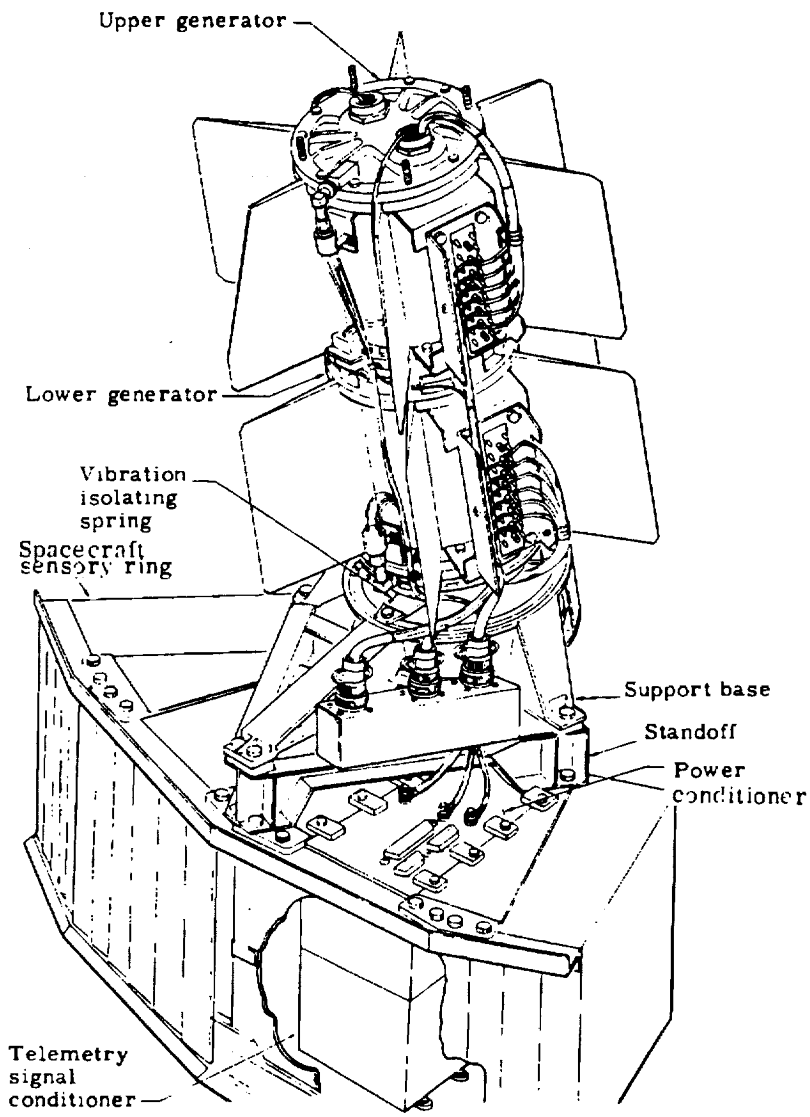


FIGURE 3 - RTG SUBSYSTEM PHYSICAL ARRANGEMENT

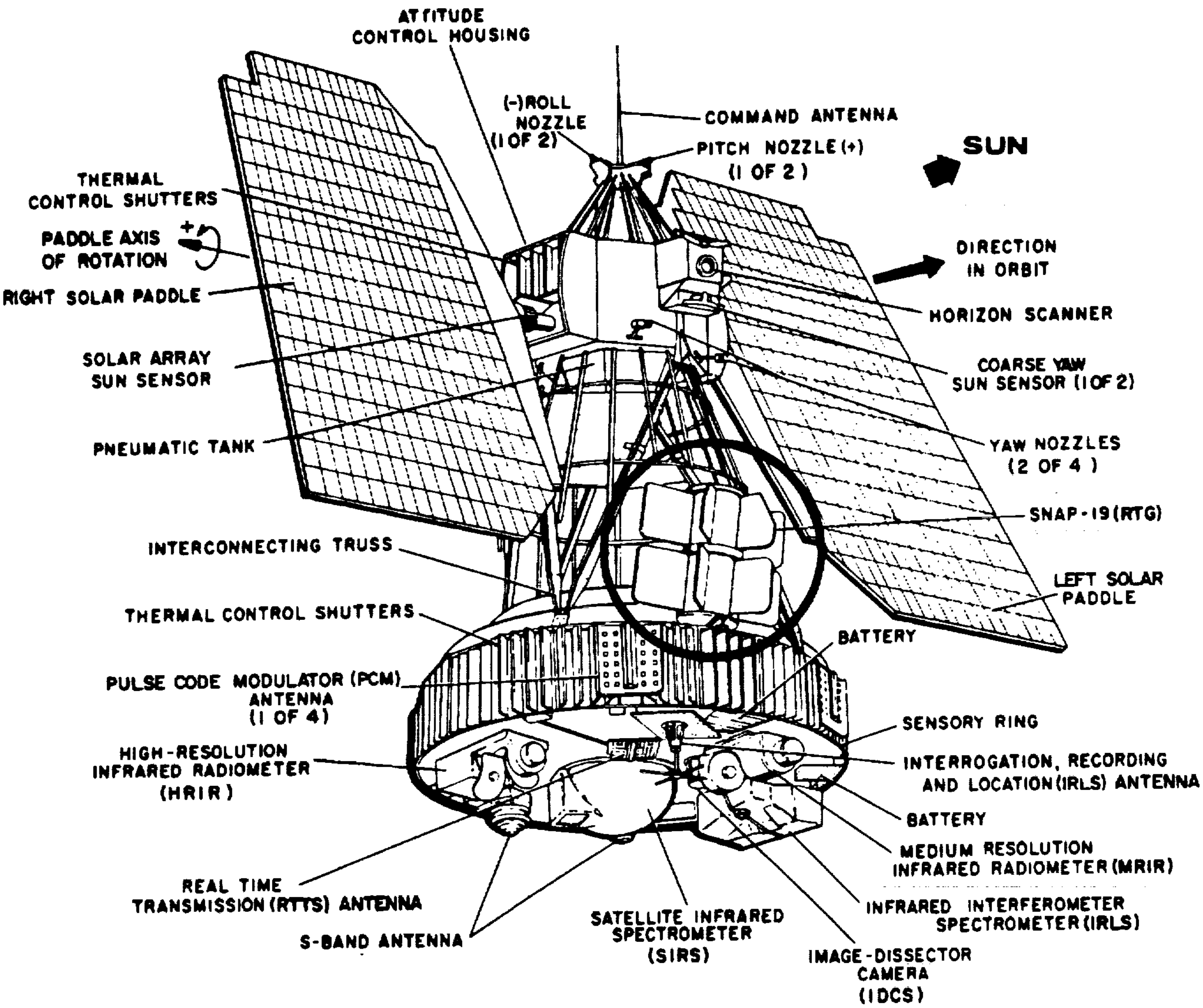


FIGURE 4 - NIMBUS III SPACECRAFT CONFIGURATION

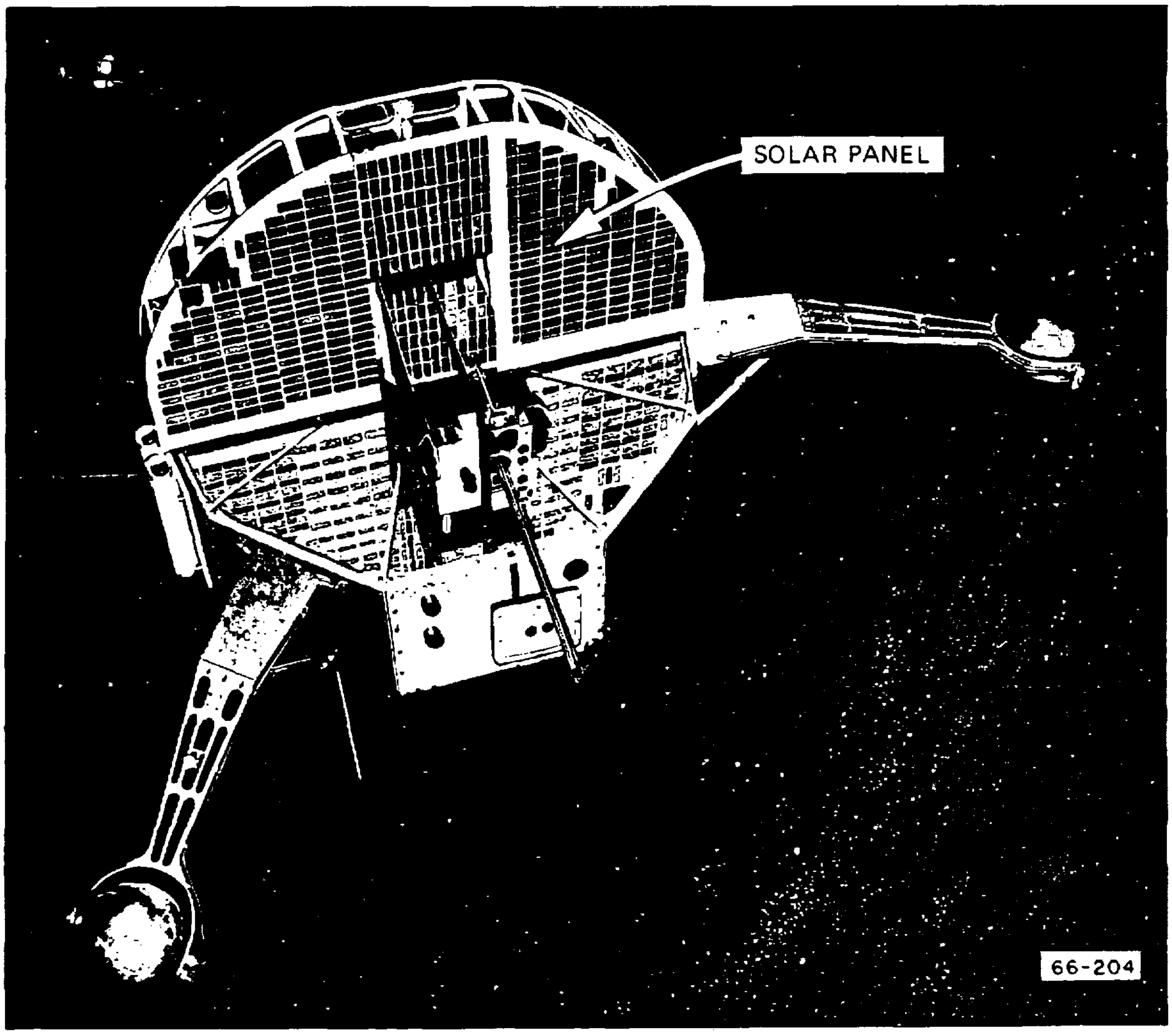


FIGURE 5 - OSO GENERAL CONFIGURATION

Item	H (in.)	W (in.)	L (in.)	wt (lb)
Directional spectrometer	6	x 6	x 12	15
70 mm Maurer camera	5-1/2	7-1/2	1-3/4	5
Film	5-1/2	x 1 dia	x 10	5
16 mm Maurer Mod 308 camera	3-1/2	1-3/4	6	2
Film	3-1/2	12	5	10
Dosimeter	6 dia	x 4 dia		1
NRL occulting disk	2	1	4	
Control sensor assembly	4	4	4	1
Right hand solar panel	22	22	2	10
HCO instrument	10	6	40	50
R.P.T. assembly	5	4	8	2
Decoder	3	x 7 dia		10
Ames plate	6	1	8	2
U. of Minn. telescopes	12	3	12	3
U. of N. Mex. foil filters	1	x 7 dia		1
GSFC-UV azimuth indexer	8	6	8	15
TOTAL				132

FIGURE 6 - OSO RETRIEVAL ITEMS

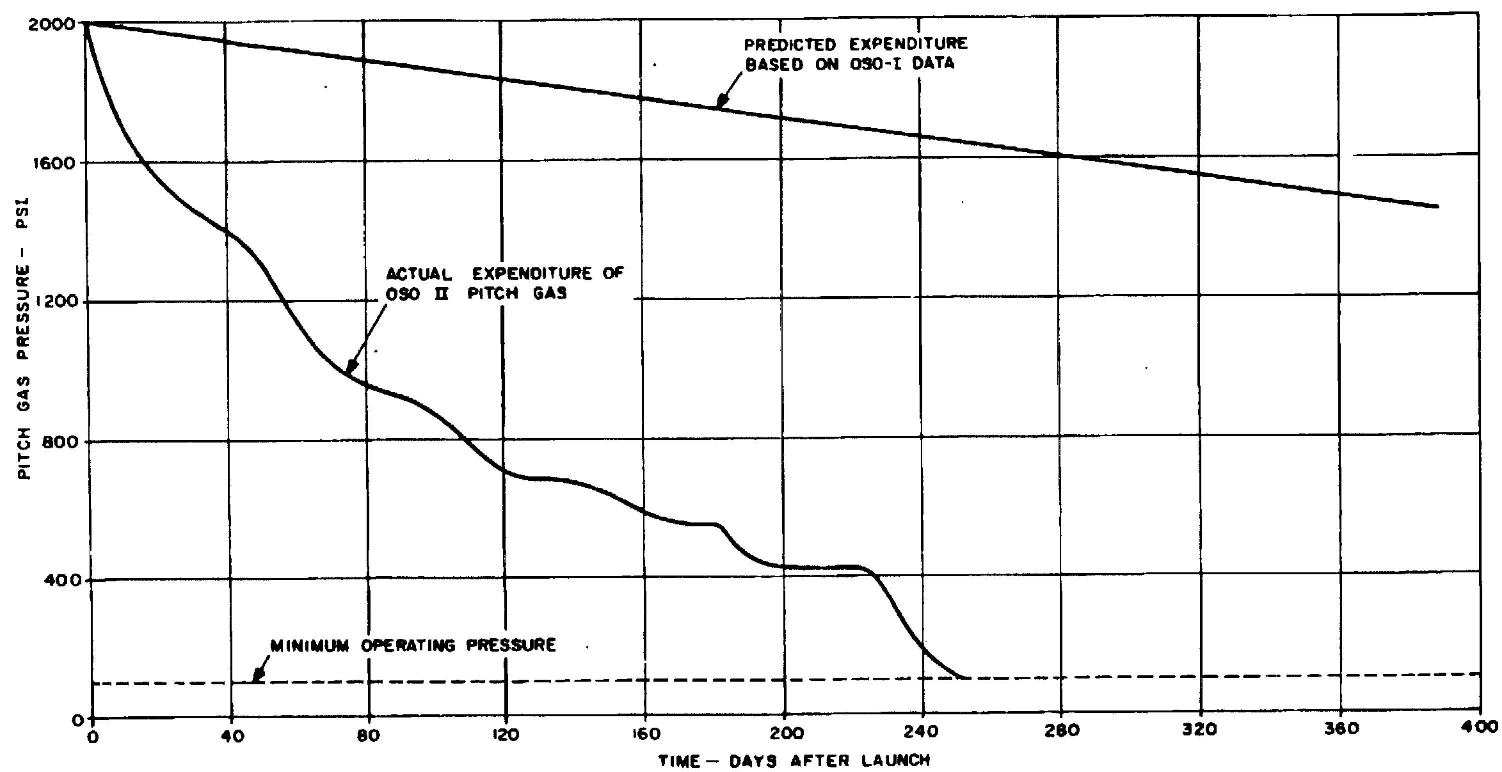


FIGURE 7 - OSO PITCH GAS EXPENDITURE

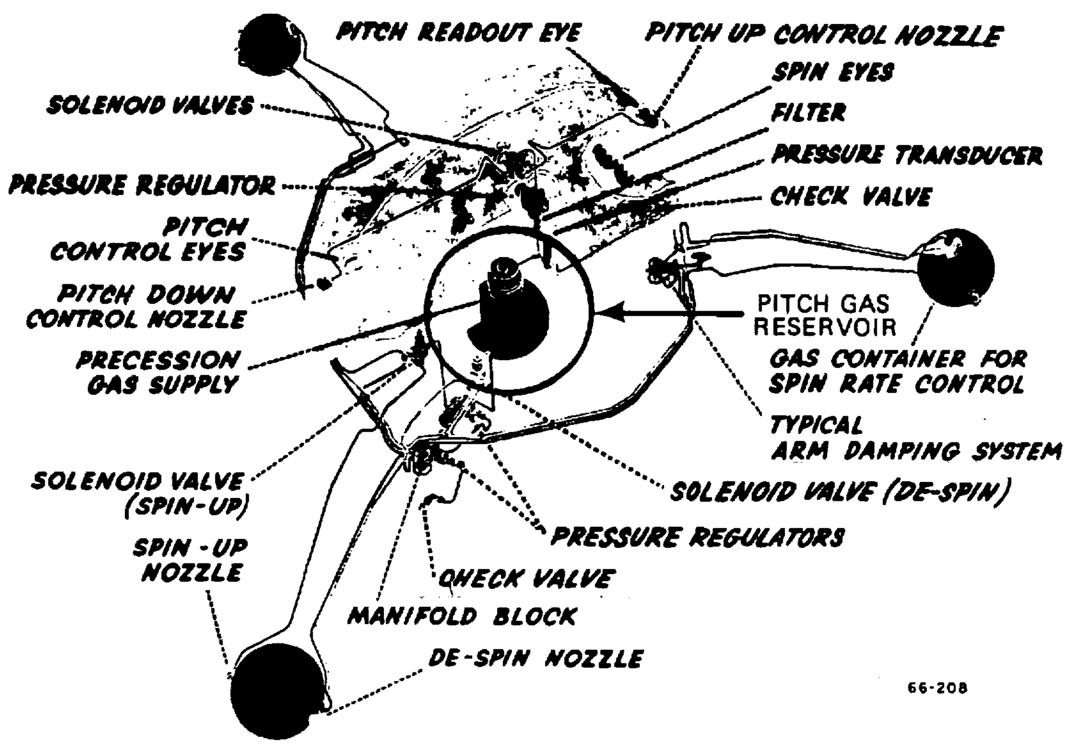


FIGURE 8 - OSO II - GAS CONTROL SYSTEMS

TACOMSAT is an experimental satellite employed to test feasibility of synchronous orbit communications with military field units, aircraft and ships. The satellite, launched by TIIIC weighs approximately 1,600 lbs, has overall dimensions of 100 inches diameter and 300 inches length. The satellite is spin-stabilized with a despun shelf containing earth pointing sensors and antennas (FIGURE 10).

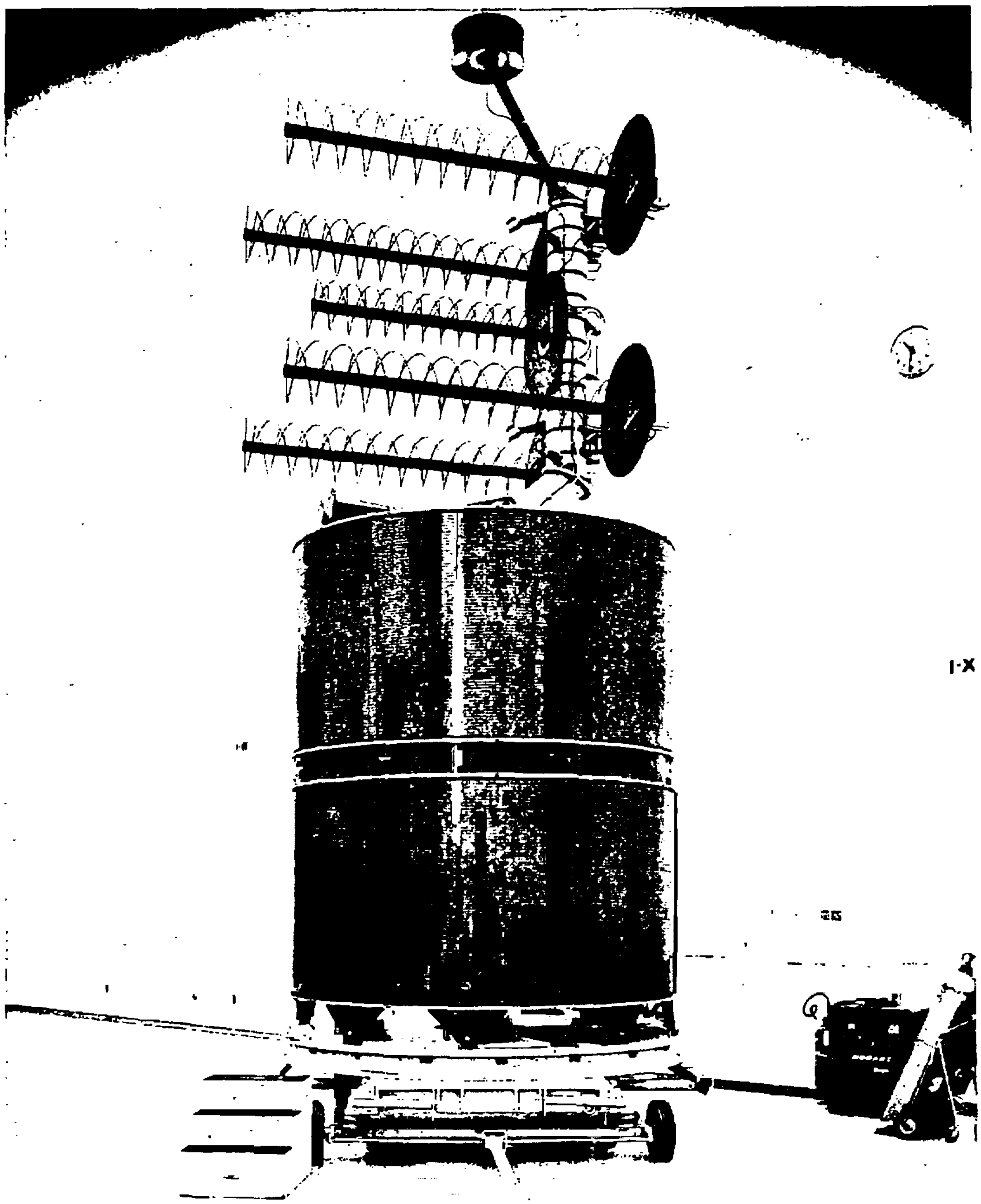


FIGURE 9 - TACOMSAT OVERALL CONFIGURATION

SATELLITE CONFIGURATION

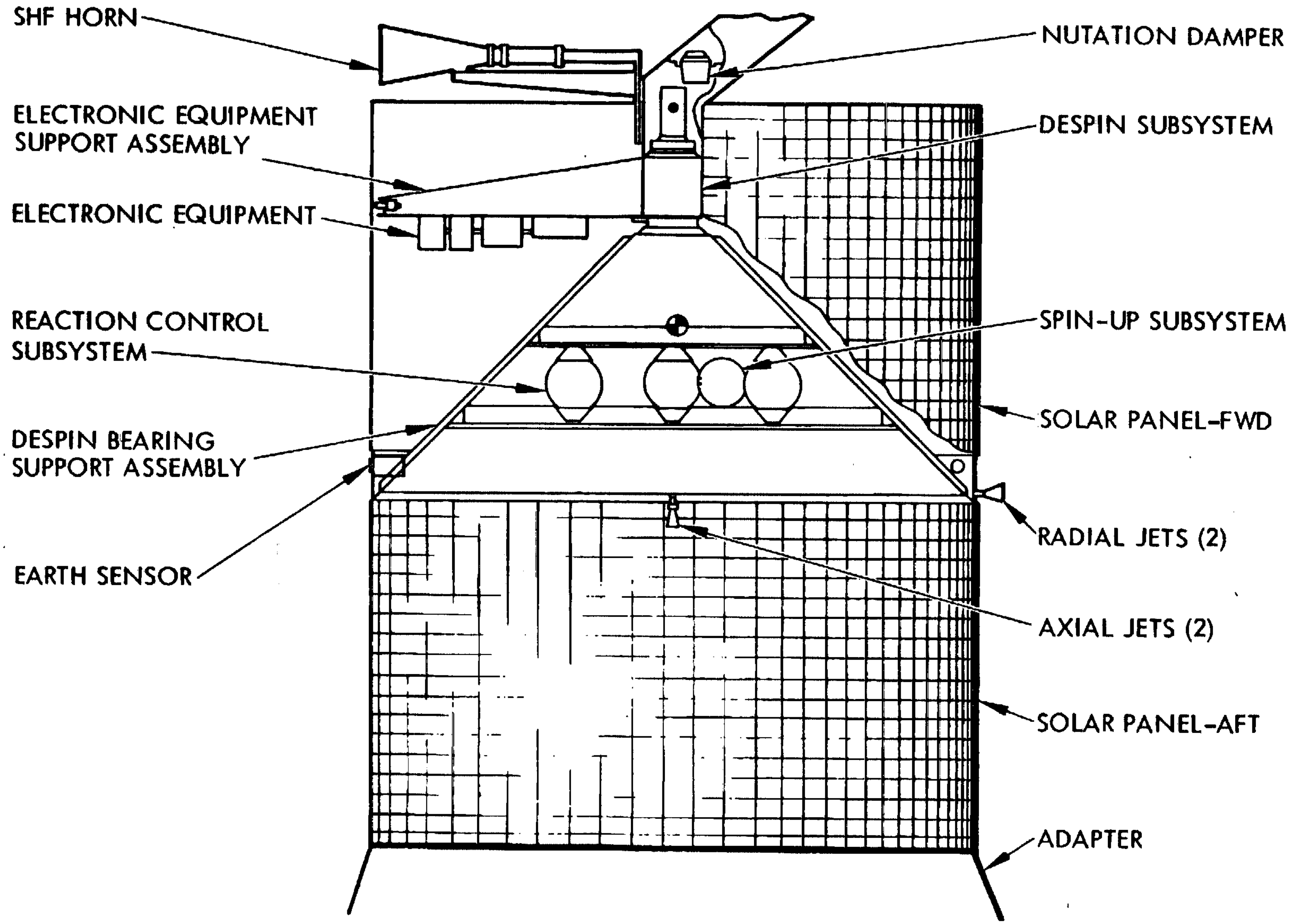


FIGURE 10 - TACOMSAT CUTOUT SECTION

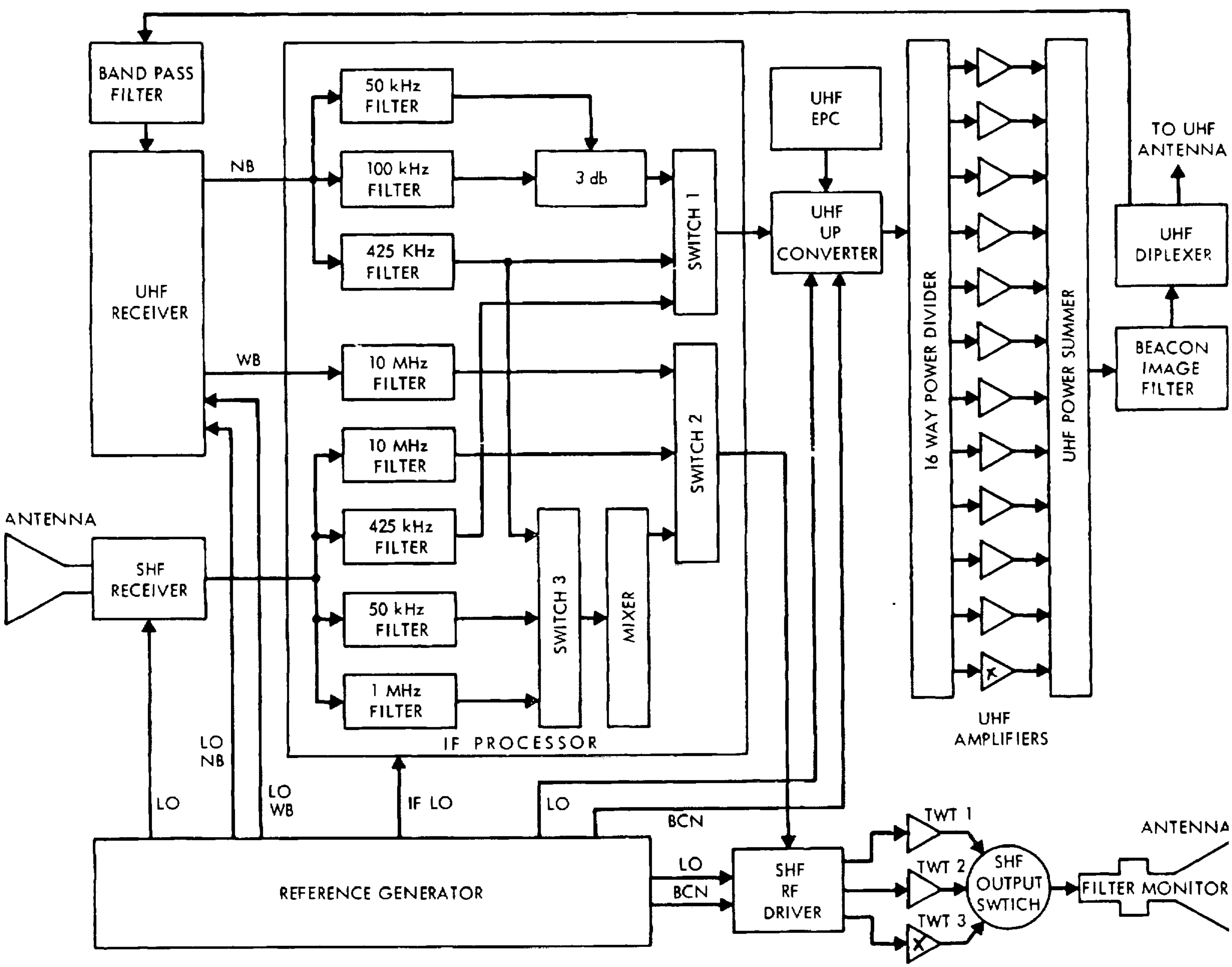


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FIGURE 11 - COMMUNICATIONS REPEATER

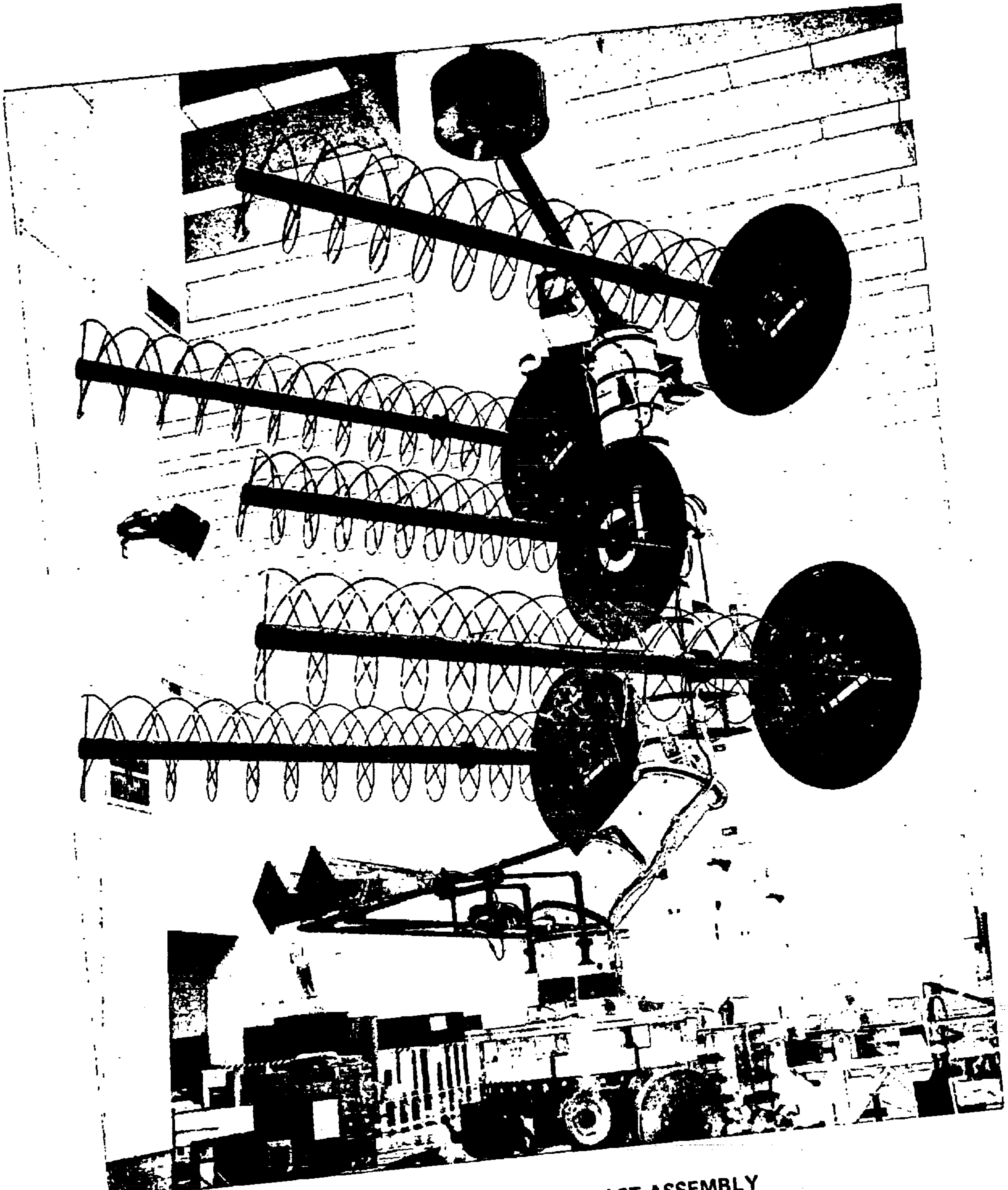
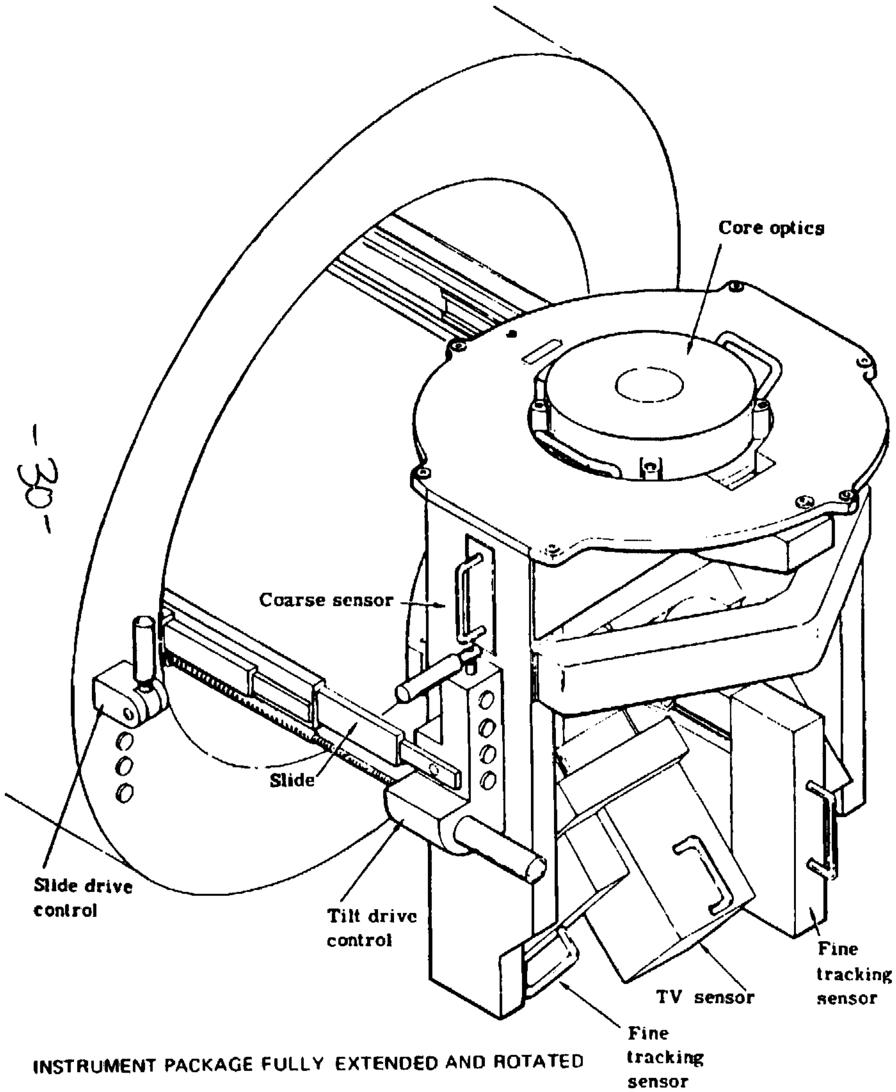


FIGURE 12 - ANTENNA-MAST ASSEMBLY

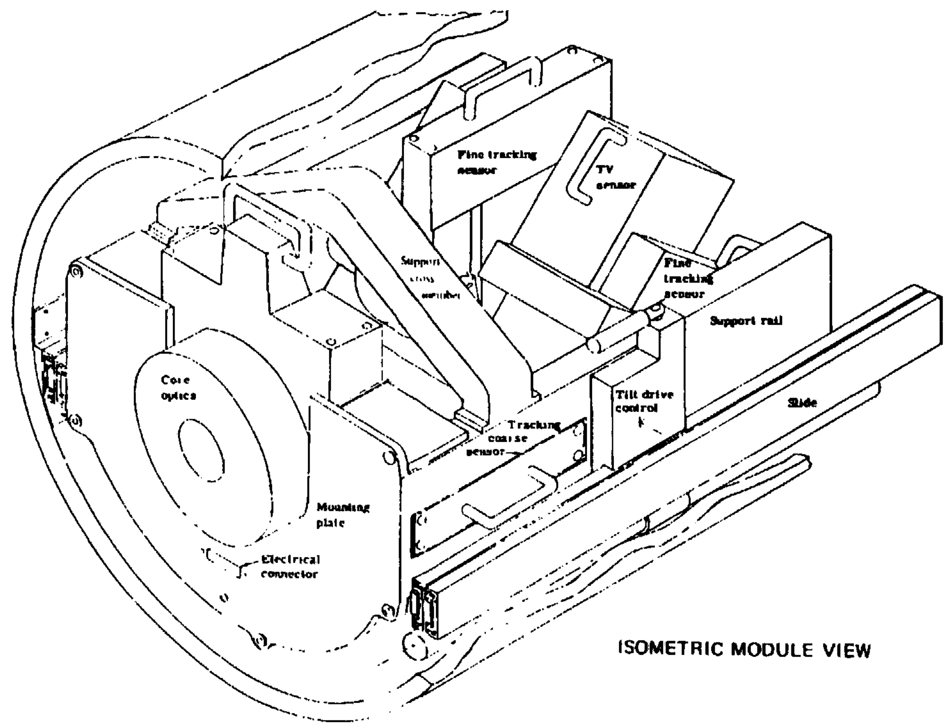
- Select natural modules on a functional basis (e.g., guidance sensor, TV tube assembly, etc).
- Establish optical tolerances to ascertain the sensitivity of the natural modules to position errors and resultant wavefront degradation.
- Establish the mechanical tolerances dictated by the optical sensitivity analyses.
- Remodularize into packages consistent with allowable optical mechanical tolerances.
- Establish the astronaut maintenance procedures
- Identify problem areas and design changes to bring the procedures within astronaut capabilities.

TELESCOPE MODULARIZATION DESIGN PROCEDURE

Figure 13



INSTRUMENT PACKAGE FULLY EXTENDED AND ROTATED



ISOMETRIC MODULE VIEW

FIGURE 14 MODULARIZED ADVANCED OAO PRINCETON EXPERIMENT PACKAGE

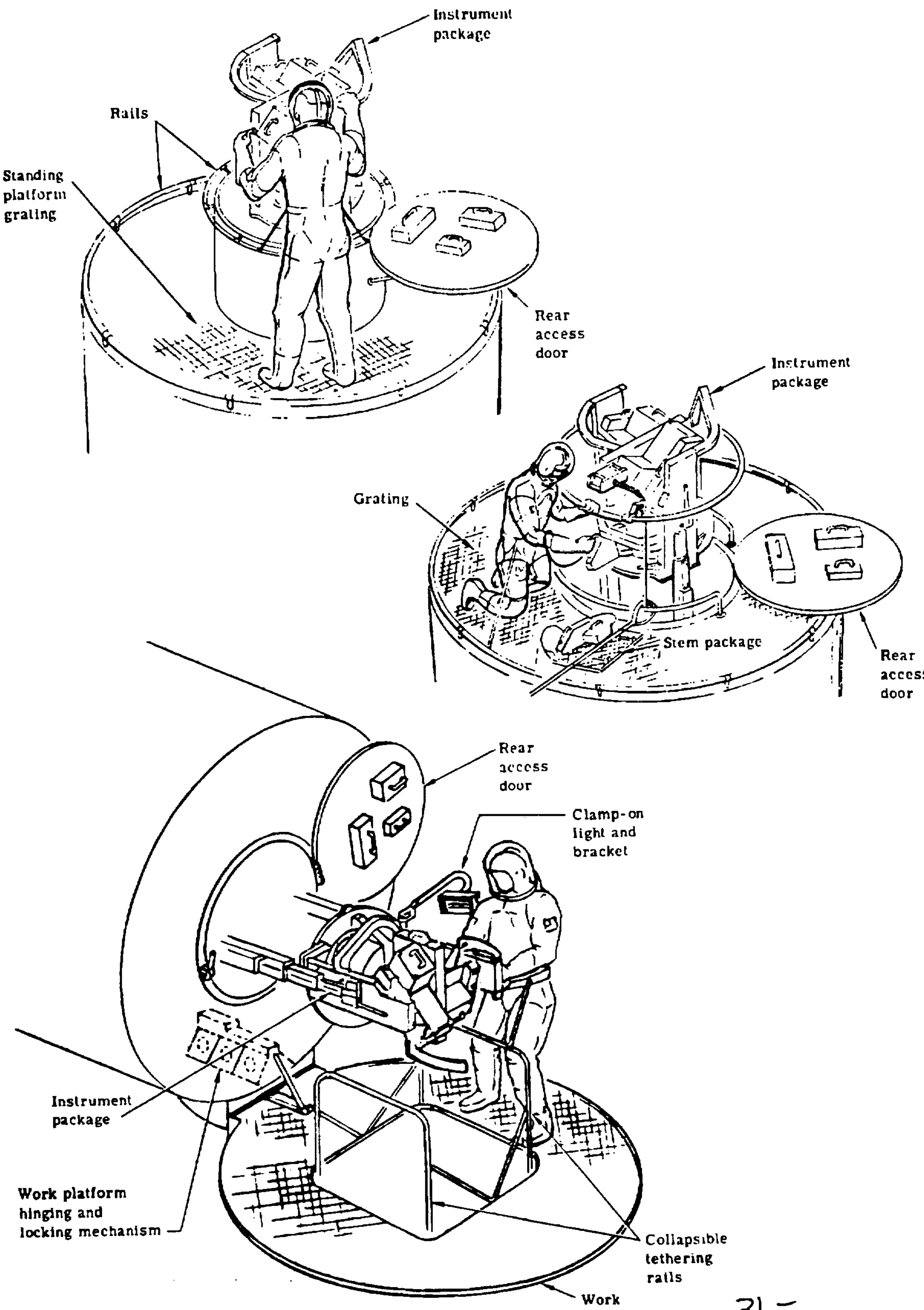


FIGURE 15 - UNSHROUDED MAN MAINTAINABLE CONCEPT

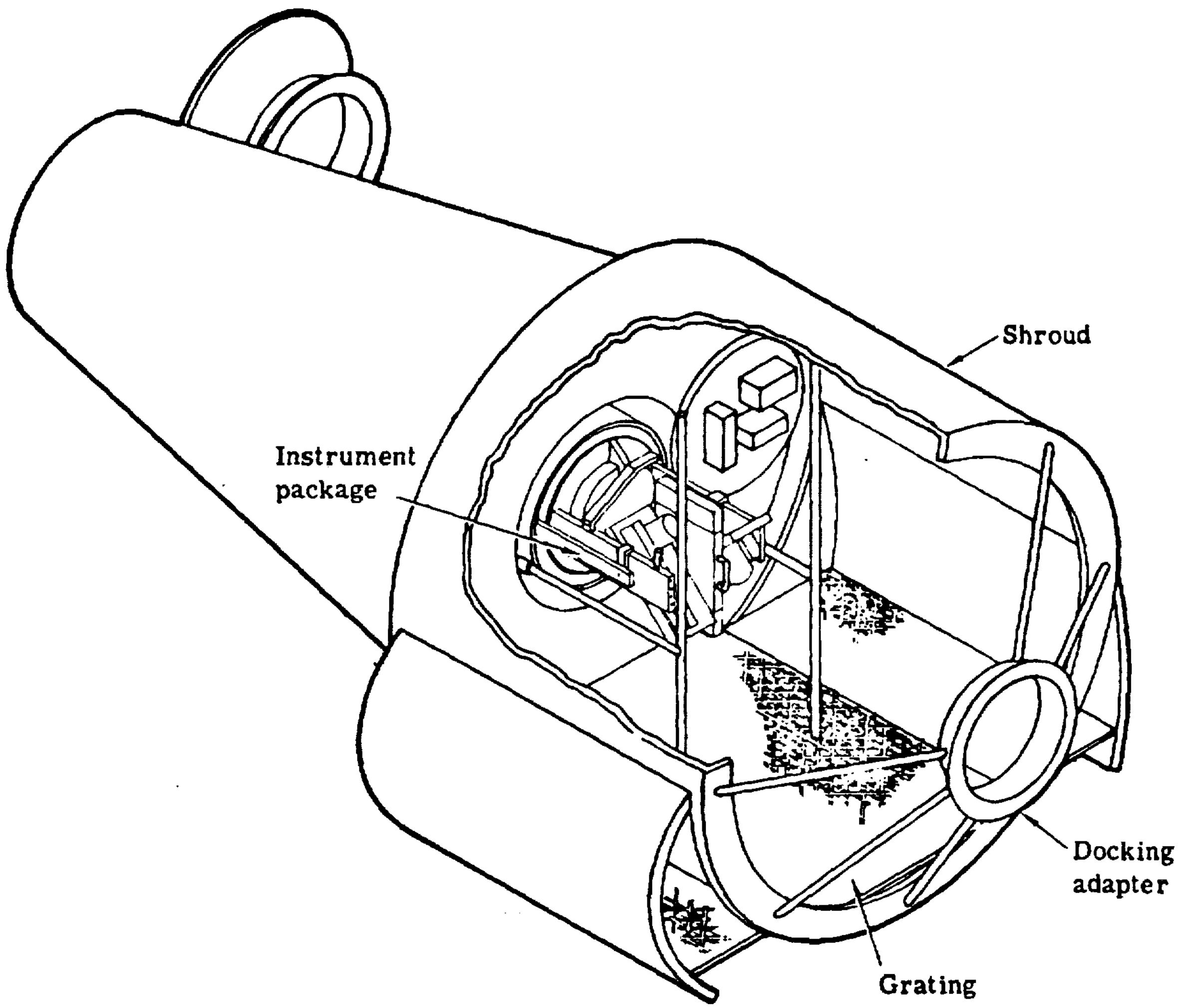


FIGURE 16 - SHROUDED MAN MAINTAINABLE CONCEPT

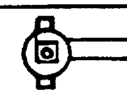
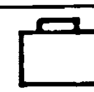
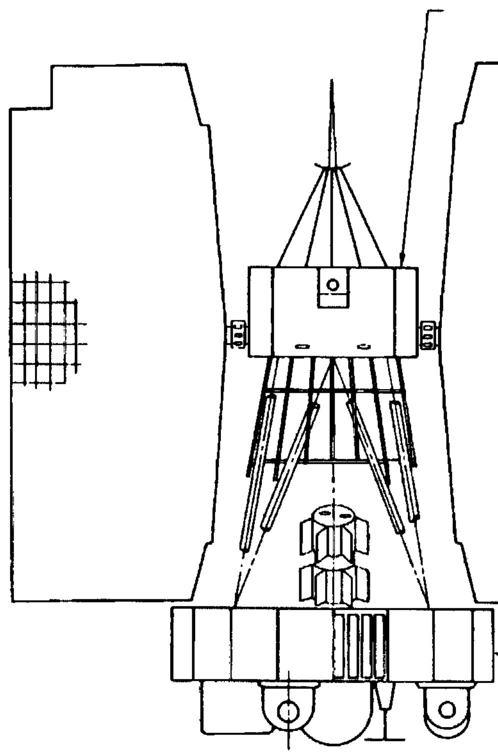
MODULE NOMENCLATURE	QUANTITY	DIMENSIONS (INCHES)	ESTIMATED WEIGHT (LB)	SKETCH
CORE OPTICS	1	15 1/2 OD X 9 3/8	30	
COARSE STAR TRACKER	2	16 X 3 X 6	15	
FINE STAR TRACKER	4	16 X 4 X 6.	15	
SEC TV SENSOR	2	7 X 8 X 17 1/2	55	
FIELD CORRECTOR GROUP	1	6 OD X 6	8	
GYRO ELECTRONICS	1	6 X 2 X 2	1	
GUIDANCE ELECTRONICS	1	10 X 4 X 3	6	
TORQUE AMPLIFIERS	1	6 X 4 X 2	3	
GYRO	1	4 X 4 X 3 1/2	3	
TELEMETRY ELECTRONICS	1	10 X 4 X 4	8	
POWER SUPPLY	1	7 X 7 X 5	12	

FIGURE 17 - LIST OF MODULES

NOTES

1. SOLAR ARRAY DRIVE AND PANELS RELOCATED
2. ACS HOUSING INCREASED IN SIZE (LENGTH ONLY)
3. TRUSS STRUCTURE RECONFIGURED
4. SENSOR RING INCREASED IN SIZE (LENGTH & DIAMETER)
5. EXPANDED VERSION APPROX. 20% LONGER
6. BASIC DIAMETER INCREASED APPROX 40%



SENSOR RING

NIMBUS III AS PRESENTLY CONFIGURED

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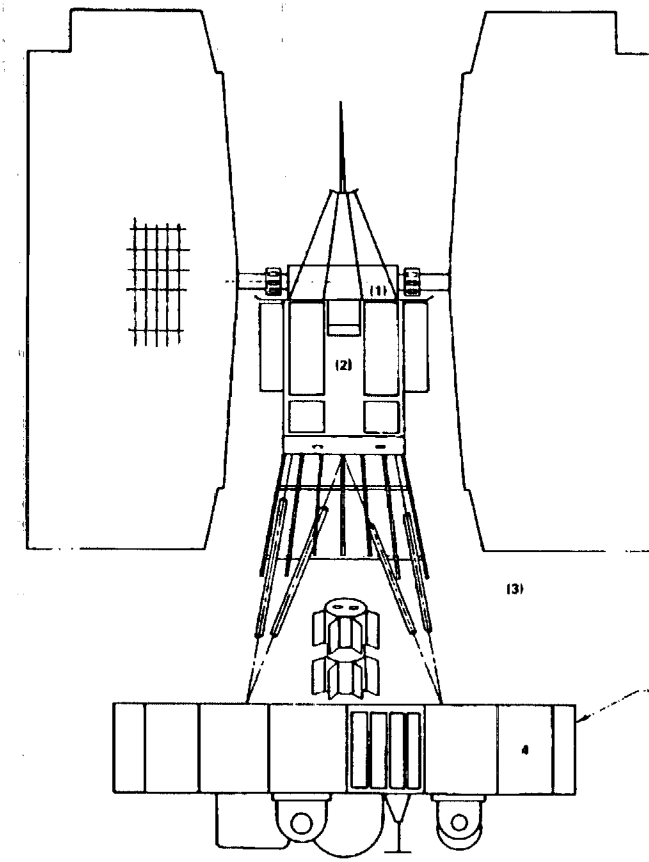
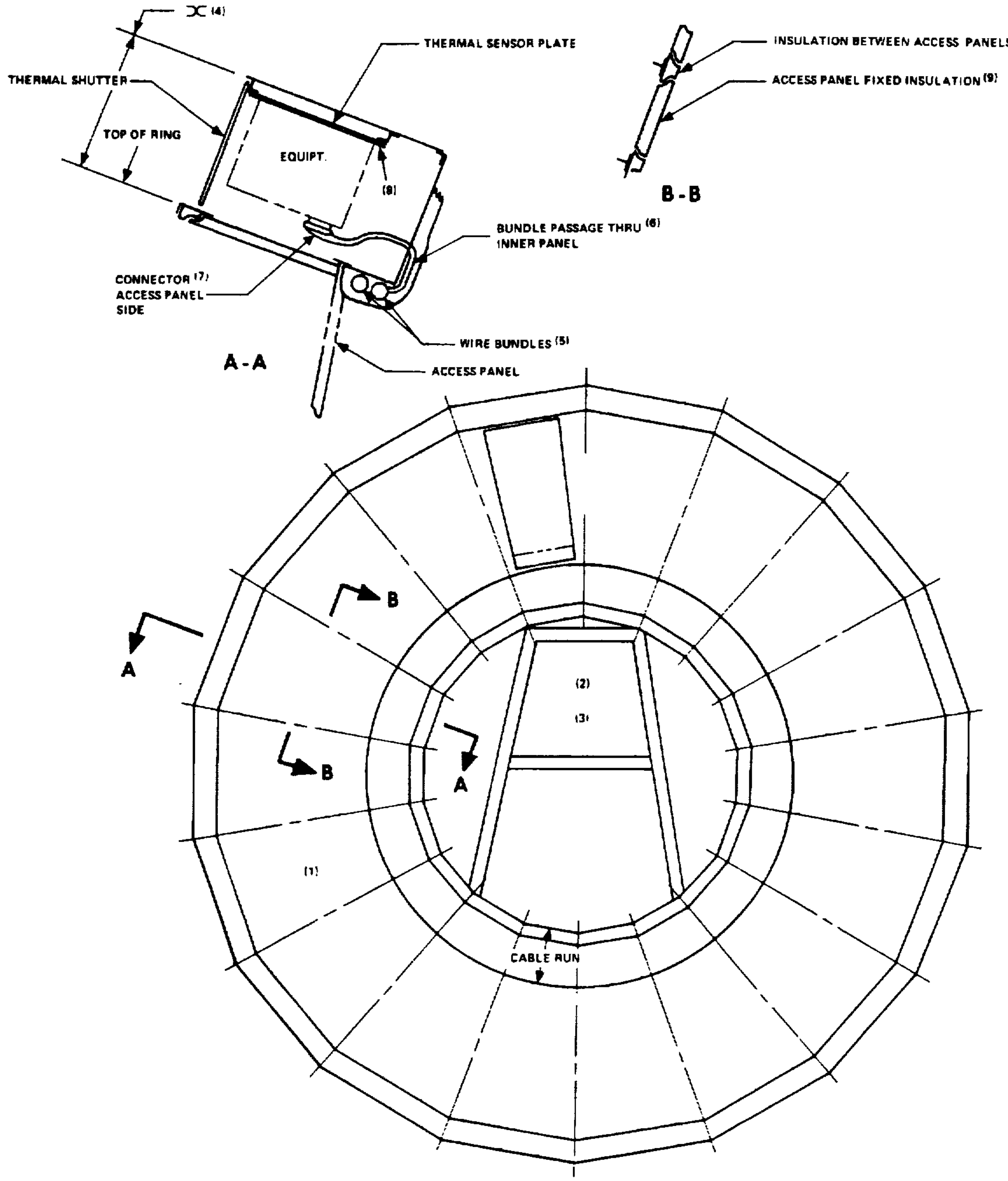


SEE FIGURE 19

NIMBUS III EXPANDED (5) (6)
CONFIGURATION

35a

FIGURE 18



NOTES

1. SENSOR RING INCREASED IN DIAMETER. RING VOLUME INCREASES FROM $11 FT^3$ TO $31 FT^3$
2. ALL EQUIPT. PRESENTLY LOCATED WITHIN SPACE FRAME INTERIOR TO SENSOR RING TO BE RELOCATED IN SENSOR RING (EXCEPT EXPTS).
3. SIZE OF SPACE FRAME AREA KEPT THE SAME AS PRESENT
4. DEPTH OF SENSOR RING INCREASED TO PROVIDE SUFFICIENT VOLUME FOR ACCESSIBILITY
5. CABLING TO BE ROUTED ALONG FIXED AREA
6. HARNESSES TO EQUIP. ROUTED ALONG INSIDE CIRCUMFERENCE TO PROVIDE ACCESS FROM INSIDE FACE OF SENSOR RING
7. ALL CONNECTORS LOCATED ON ACCESS PANEL SIDE OF EQUIPT. FOR ACCESSIBILITY & READY DISCONNECT
8. EQUIPT. ATTACH FASTENERS, CAPITIVE TO UNIT, ARE ACCESSIBLE FROM PANEL SIDE
9. INSULATION REVISED TO PROVIDE FIXED INSULATION ON ACCESS PANELS OVERLAPPING ADJOINING INSULATION
10. ACCESS TO SHUTTER SYSTEM THROUGH EQUIPT ACCESS PANELS

FIGURE 19 - NIMBUS SENSOR RING CONFIGURED FOR SERVICING & MAINTENANCE OF EQUIPMENT.

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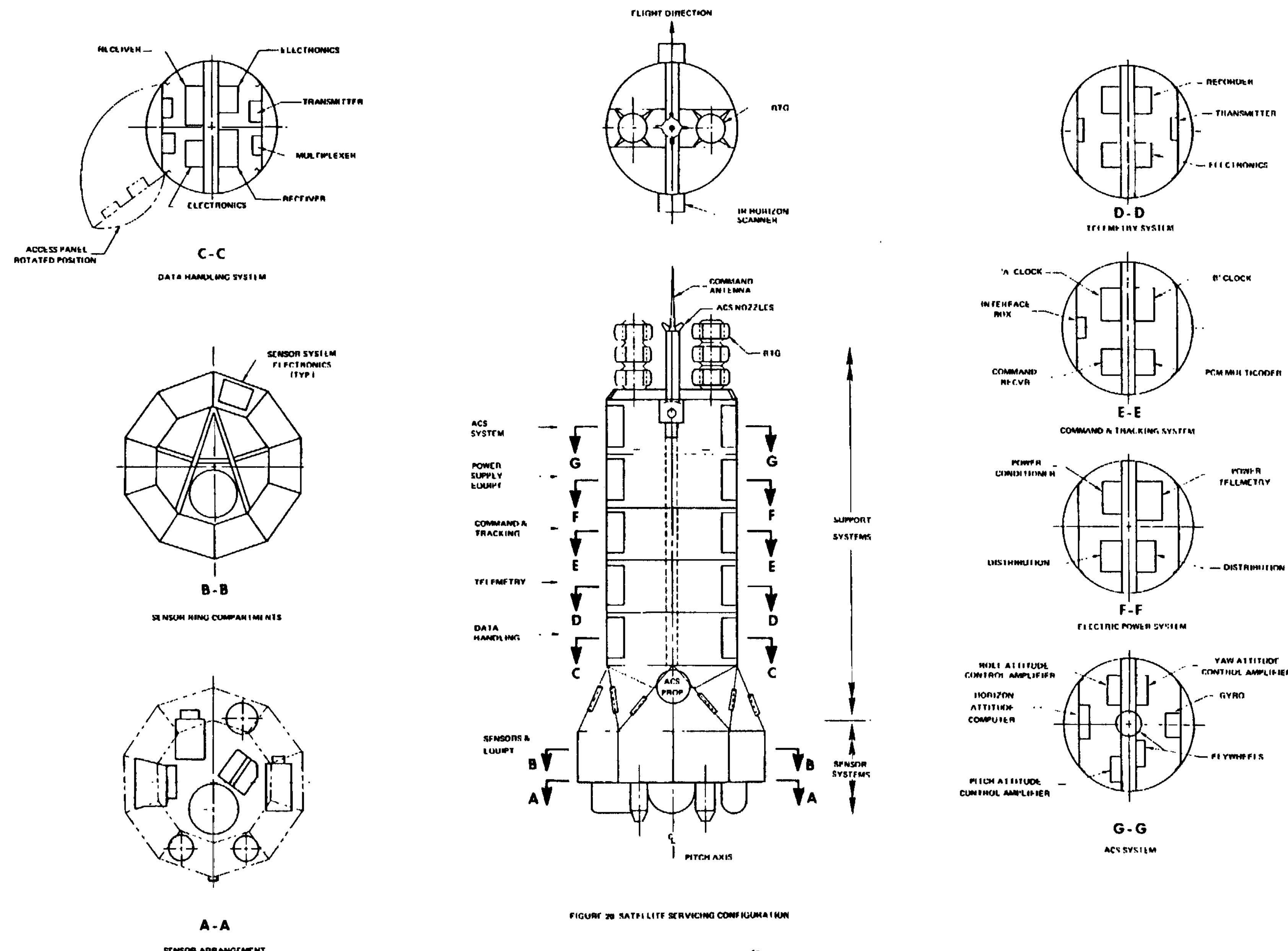

FIGURE 28 SATELLITE SERVICING CONFIGURATION

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1 37a-